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Mission Design Analysis of the SolSat CubeSat

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Abstract

SolSat is the third CubeSat mission for the Sharjah Academy for Astronomy, Space Sciences, & Technology. The scientific goal of the small satellite is to monitor the Earth's Ionosphere's daily behavior due to the Sun's activities and collect valuable data on its condition at the LEO (low earth orbit) level. This new mission will introduce the UAE to the space weather research field and help set its policy toward adverse space weather effects while advising the aviation authority on space weather hazards. It will also allow the UAE to contribute to the international effort to mitigate space weather effects on our human civilization. In addition, the mission data could set up early warning systems to prevent electrical power grid, radio, and GPS blackouts due to solar storm effects. When designing such a complex space mission, many factors must be considered in the early phases before implementing, selecting, and procuring components. This can be achieved through simulations and modeling of the system. Such considerations include Orbit Determination, Lifetime Analysis, Power Generation/Consumption, access times, and durations. These factors can help improve our understanding of the subsystem requirements, aid in the decision-making process through a practical trade-off analysis and bind us to decide on factors that constrain our mission and ensure its success. This paper will discuss the utilization of the Systems Tool Kit (STK), a tool used to model systems in all domains of operation, such as Air, Space, Ground, and Sea. We will perform the following simulations to aid mission design: (i) orbit analysis to estimate the best orbit for our mission regarding communication windows, (ii) lifetime analysis to assess the visibility of our satellite in space, and (iii) power generation to estimate the power produced by the chosen solar panel configuration and evaluate it against the subsystem requirements in terms of power demands. The objective of this paper is to evaluate and analyze two altitudes: 500km and 600km, in a Sun-Synchronous Orbit (SSO) at three different Local Times on the Ascending Node (LTAN): 6 AM, 9 AM, and 12 PM.

Keywords: CubeSat, Mission Design, Space Weather, Particle Detector.

Acronyms/Abbreviations

Solar Particle Detector (SPD), International Space Station (ISS), System Tool Kit (STK), Solar Energetic Particle (SEP), Low Earth Orbit (LEO), Sun-Synchronous Orbit (SSO), Local Time ascending Node (LTAN), Sharjah Academy for Astronomy, Space Sciences, & Technology (SAASST), University of Sharjah (UOS).

1. Introduction

The Sharjah Academy for Astronomy, Space Sciences, and Technology (SAASST) has successfully launched its first-ever CubeSat mission, Sharjah-Sat-1, which is a 3U CubeSat with an improved X-Ray detector payload. As part of a series of CubeSat missions, SAASST plans to launch a small satellite dedicated to monitoring the Earth's Ionosphere called SolSat. Such a mission would provide data of significant importance to the space weather research field, achieved by the novel payload onboard, a Solar Particle Detector (SPD). This innovative instrument would cover a wide range that has not been previously covered by a satellite of this scale, which is 0.1-100 MeV and would fit in the proposed 6U structure. Another space weather-focused mission, the Colorado Student Space Weather Experiment (CSSWE), was launched by the University of Colorado (CU) in 2012. This 3U CubeSat housed the Relativistic Electron and Proton Telescope "integrated little experiment" (REPTile) for directional differential flux measurements of 0.5 to >3.3 MeV electrons and 9 to 40 MeV protons. It was launched into an elliptical orbit (478km × 786km) with an inclination of 64.7˚ [1]. A consecutive mission planned to be launched in early 2023 is the Colorado Inner Radiation Belt Experiment (CIRBE). It is a 3U CubeSat with a Relativistic Electron Proton Telescope integrated little experiment – 2 (REPTile-2) instruments onboard to measure incident electrons and protons energies. The payload targets the range of .3-3.5 MeV for electrons and 6-35 MeV for protons, and the CubeSat is planned for a highly inclined Low Earth

Orbit [2]. To achieve the scientific mission objectives of SolSat, the appropriate orbital parameters must be selected through a careful study. This is part of the mission analysis outcome, an activity that takes the payload operational requirements and the satellite as a whole into consideration. This combines the selection of the CubeSat dimensions, the ground station visibility, the ground coverage, and the orbital lifetime [3].

This paper is organized as follows. In section 2 of this paper, we present the mission objectives of SolSat. Section 3 discusses the mission analysis in terms of the different approaches of access time, lifetime analysis, and power production. The results are presented in section 4 of the paper and thoroughly discussed in section 5. Lastly, the conclusion of the study is showcased in section 6.

2. Mission Objectives

The primary purpose of the new mission system and its accompanying solar particle detector is to advance two distinct scientific objectives. The primary scientific objective of SolSat is to gain a thorough understanding of the potential dangers posed by high-velocity electrons with energies that exceed a couple of millions of electron Volt (MeV). The second objective of the system is to seek the analyze of the activity of the solar flares and their impact on the solar energetic particle event during the 11 years solar cycle. Through this mission, scientists hope to acquire a better understanding of how these flares impact space weather and the Earth's environment. In addition, the system is also designed to help develop the human capabilities necessary to design, build, test, and incorporate space systems and sensors, which is an important strategic goal.

3. Mission Analysis

Mission design analysis is an essential step in developing a CubeSat mission as it enables the identification of potential technical and operational challenges and the assessment of the feasibility and cost-effectiveness of the mission. The analysis also allows optimizing the mission design to meet specific objectives and constraints. In addition to the simulation of the CubeSat's orbit in order to predict the performance of the satellite in different orbits, providing valuable insights into the trade-offs between different altitudes and helping to make informed decisions on the most suitable orbit for the specific mission requirements and objectives.

Systems Tool Kit (STK) is a powerful software suite developed by Analytical Graphics Inc. (AGI) that allows analyzing and simulating complex systems such as satellite system missions [4]. It is widely used in aerospace applications and the defense industry to plan the mission, analyze the orbits, and build a ground-based system. In this paper, STK is used to analyze a 6U CubeSat mission orbiting in a sun-synchronous orbit. Two altitudes have been taken into consideration: 500km and 600km, with three possible LTAN values: 6 AM, 9 AM, and 12 PM. The conducted analysis concentrated on three main factors: the satellite lifetime, the access times over SAASST, and the amount of generated power.

3.1 Orbit Parameters

Orbital selection acts as a critical function during the mission design process. The Sun-Synchronous Orbit (SSO) allows the satellite to pass over the same location at the same local time daily [5]. Thus, this orbit has been considered for this mission analysis in this paper. Furthermore, the SSO altitude also affects the access time, which means as the altitude reduces, the passing time being shorten. The used orbital parameters for the STK scenario are listed in Table 1.

Table 1. SolSat Orbital Parameters

Propagator	HPOP					
Altitude	500 km			600 km		
LTDN	06:00:00	09:00:00	12:00:00	06:00:00	09:00:00	12:00:00
RAAN	169.544	2144.544	259.544	169.544	2144.544	259.544

3.2 Access Time Analysis

The access time of the satellite is the assumed duration for that satellite to establish a communication connection with the ground station for transmitting and receiving data [6]. This means we can communicate with our satellite while it passes over our SAASST's ground station with a latitude and longitude of 25.2851° and 55.4609°respectively. A cubic satellite is designed typically to be operated between 400km to 600km [7]. The altitude of the satellite is the average distance between both centers of the earth and the spacecraft's orbit. Many factors affect the access time, such as the CubeSat position, weather conditions, and atmospheric drag. It is necessary to know that gravity is not the only earth factor impacting satellite communication; the earth's atmosphere layer also plays a crucial role [8]. Here, an estimated STK analysis has been made to predict SolSat passes over the emirates of Sharjah. Hence, the pass duration varies between a few minutes to several hours based on the orbital parameters.

3.3 Lifetime Analysis

A satellite's lifetime refers to how long the spacecraft can continue to operate as intended before D-orbiting and becomes inoperable, which means it is the CubeSat duration at which it functionally works. These include the orbit stabilization phase, the space-ground communication period, and performing the objective mission period. CubeSats have a relatively short lifetime in space due to their limited power generation and in-space propulsion capabilities [9]. As a result, most CubeSat projects are designed to be operated for between two to five years only [10]. Additionally, the CubeSat lifetime can be limited by the period the mission objectives are planned for. Once the scientific objectives are achieved, the CubeSat will reach its end-of-life phase [9].

In this section, STK software is used to predict SolSat lifetime at various altitudes and LTANs, considering the atmospheric drag, the solar radiation pressure, and the drag coefficient.

3.4 Power Production

The current design of the SolSat mission is equipped with a body-mounted solar panel configuration in order to produce the required power to run all the subsystems, including the payload. This configuration is utilized to keep the design more feasible and simplified. In STK, the solar panel tool is used to calculate the estimated average power per orbit for the proposed orbit with different altitudes and LTANs, taking into consideration the collected amount of sunlight, the orientation of the CubeSat, and the efficiency of the panels. This step is significant in the initial phase of planning and designing any CubeSat mission in terms of preparing the power budget calculations. Figure 1 shows the STK standard 6U CubeSat model with body-mounted solar panels.

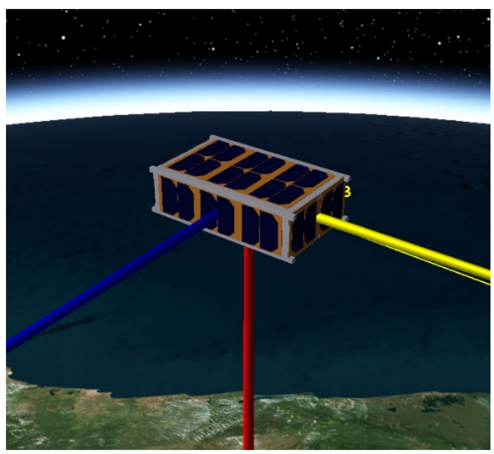

Figure 1. SolSat model

4. Results

This section displays the obtained results using STK software for two different altitudes: 500km and 600km, taking into account three local ascending times: 06:00 AM, 09:00 AM, and 12:00 PM. The orbital parameters were summarized in the previous section, Table 1. As recommended, the HPOP (high-precision orbit propagator) is the one used for the simulation [11]. As the CubeSats' optimal orbits are in LEO, these two altitudes were selected. Likewise, the three LTANs were chosen based on the launch constraints, such as the available launch windows and sites [12]. These six scenarios were compared to get the best lifetime, access time, illumination time, and power generation results. Table 2 illustrates the obtained results.

Table 2. STK Results

Analysis Orbital Parameter						
Propagator	HPOP					
Altitude	500 km			600 km		
LTAN	06:00:00	09:00:00	12:00:00	06:00:00	09:00:00	12:00:00
RAAN	169.544	2144.544	259.544	169.544	2144.544	259.544
Lifetime Analysis						
Expected Lifetime (years)	9.4	10.3	10.2	46.5	45.6	37.4
Access Time						
Average Duration per Access (s)	569.5	555.8	556.5	657.4	648.5	647.1
No of accesses per day	4-5	4-5	4-5	5	5	5
Power Generation Analysis (per Orbit)						
Average Power (W)	12.72	10.86	10.39	13.16	11.11	10.57
Maximum Power (W)	17.84	17.92	17.92	17.83	17.83	17.81
Duration of the Orbit (min)	94	94	94	96	96	96
Illumination period (min)	72	61.5	35.5	76.5	64	35

5. Discussion

This section briefly discusses the simulation results and presents the optimum orbit based on the trade-off analysis between various parameters that fit the requirements. It clearly shows that the estimated lifetime of all three LANT is almost the same for each altitude, resulting in sufficient lifetime periods. Hence, normally a CubeSat lifetime is between three to five years. Furthermore, all six scenarios pass over Sharjah around four to five times daily, where the average pass duration is from 550s to 660s for 500km and 600km altitudes, respectively. Additionally, the average generated power in all cases is similar for both altitudes and various TLANs. This amount of the produced energy by the mounted solar panels is to be more investigated and simulated based on the CubeSat requirements. The minimum obtained average power is 10.39W per orbit, while the max is 12.72W. Moreover, the maximum production power at a specific time and orientation are almost 17.80W. This power generation analysis is conducted per orbit to simulate the actual space environment, where the CubeSat experiences sunlight and eclipse during each orbit. Each orbit takes around 94 to 96 minutes. It could be clearly noticed that the power is independent of the altitude value and the LTANs, and these slight differences are due to the orientation of the satellite at that time and could be neglected. As the orbit's illumination period increases, the power generation period and the incident solar radiation on the solar panels increase, and vice versa. However, this could cause thermal management issues, which is super critical in CubeSats as the design is very constrained to add an active control thermal management unit. For instance, The CubeSat in orbit with LTAN at 6:00 AM is exposed to sunlight for nearly 80% of its orbital duration for both altitudes. Hence, the most suitable orbit is when the LTAN is 9:00 AM for both altitudes.

6. Conclusions

In summary, SolSat is a CubeSat mission of six units in size with the aim of improving the space weather research area by detecting solar particle energy using the newly developed detector (SPD). As a critical phase, analyzing of the designed mission is performed and discussed, showing six scenarios for selecting the optimal orbit. As mentioned previously, the result and discussion show that all the simulated situations suit our system, and the chosen orbit is an SSO with 600km altitude at 09:00 AM LTAN. Mainly, the illumination time makes a difference and determines the approver orbit. Finally, further analysis may conduct if the system requirements require.

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References

[1] Gerhardt, D. et al. (2013) "The Colorado Student Space Weather Experiment (CSSWE) On-Orbit Performance," Journal of Small Satellites, 3, pp. 265–281.
[2] (2022) CIRBE. Available at: https://lasp.colorado.edu/home/cirbe/ (accessed: 05.01.23).
[3] Fortescue, P., Swinerd, G. and Stark, J. (2011) Spacecraft Systems Engineering. Chicester: Wiley.
[4] AGI, "Systems Tool Kit (STK)," https://www.agi.com/products/stk/
[5] Paek, S. W., Kim, S., Kronig, L., & de Weck, O. (2020). Sun-synchronous repeat ground tracks and other useful orbits for future space missions. *The Aeronautical Journal*, *124*(1276), 917–939. https://doi.org/10.1017/aer.2020.21
[6] Salimi, M. *et al.* (2015) "Maximum access time for an earth stations network," *2015 7th International Conference on Recent Advances in Space Technologies (RAST)*.
[7] Villela, T. *et al.* (2019) "Towards the thousandth Cubesat: A statistical overview," *International Journal of Aerospace Engineering*, 2019, pp. 1–13.
[8] Palmer, P., & Mai, Y. (2000, January). *SSC 00-VI-5 a fast prediction algorithm of satellite passes*. Semantic Scholar, https://www.semanticscholar.org/paper/SSC-00-VI-5-A-Fast-Prediction-Algorithm-of-Passes-Palmer-Mai/5c3a4839fa7627839e032c7a6cec4ceba3b7b589
[9] King-Hele, D. G, Satellite Orbits in an Atmosphere: Theory and Application, 1987.

[10] Gallois, P. (1987). Life expectancy of communication satellites. *Electronics and Power*, *33*(9), 547.

[11] Refaat, A., Badawy, A., Ashry, M., & Omar, A. (2018). High accuracy spacecraft orbit propagator validation. *The International Conference on Applied Mechanics and Mechanical Engineering*, *18*(18), 1–9.
[12] Larson, W. J., & Wertz, J. R. (Eds.). (1992*). Space mission analysis and design* (Vol. 3). Torrance, CA: Microcosm.